Bioacoustic Absorption Spectroscopy

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LONG-TERM GOAL

Demonstrate the potential of bioacoustic absorption spectroscopy for tomographic mapping of the bioacoustic parameters of fish with swim bladders in shallow water.

OBJECTIVES

Develop a sound propagation model that accounts for bioacoustic absorptivity due to fish with swim bladders on transmission loss as a function of frequency over the frequency range 0.5- 5.0 kHz in shallow water.

Develop a bioacoustic model that accounts for the resonance frequencies and Q's of absorption lines, which are due to dispersed pelagic fish and schools of pelagic fish with swim bladders.

Demonstrate consistency between inverted magnitudes of bioacoustic parameters from long range transmission loss measurements and direct measurements of these parameters. In particular, demonstrate consistency between inverted and direct measurements of average lengths and depths of fish and their number densities. Document comparison of number densities inverted from absorption spectroscopy measurements and echo sounder and trawling data.

Design a low cost, long term, large bandwidth measurement system to permit routine measurements of transmission loss over a large bandwidth over long periods of time from one source to multiple, widely spaced receivers in littoral seas to permit tomographic mapping of biological populations at mesoscale ranges.

APPROACH

Invert bioacoustic parameters from transmission loss data recorded during Modal Lion, by matching theoretical computations with data. Demonstrate consistency through comparison of inverted parameters with concurrent echo sounder measurements of depth and trawling measurements of fish length distributions. Develop an analytical model to account for the frequencies and Q's of measured absorption lines by extending a previously published theory of the resonance frequency of "bubble clouds".

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WORK COMPLETED

The resonance frequencies of absorption lines attributed to sardines were calculated over the entire frequency range of Modal Lion data. A theoretical model of the resonance frequencies of "bubble clouds", which is valid when the separation, s, to wavelength, λ_0, ratio is very small ($s / \lambda_0 < 0.06$), was extended to permit computations of resonance frequencies for larger separations ($s / \lambda_0 \approx 0.3$), which are representative of fish schools. This model is valid for realistic values of the total number of fish per school, which is generally on the order of 10^4 to 10^5.

RESULTS

Measured frequencies of absorption lines, which were attributed to juvenile (~ 3.9 kHz) and adult sardines (~ 1.3 khz), were demonstrated to be consistent with calculated frequencies, which were based on direct measurements of the bioacoustic parameters of adult and juvenile sardines. This is an important result, since isolation of juvenile from adult pelagic fish is difficult with traditional echo sounder methods (which generally employ measurements made at a single frequency, ~ 40 kHz).

The depth dependence of measured resonance frequencies was shown to be consistent with Boyle's law. Systematic changes in resonance frequency were consistent with echo sounder measurements of vertical migrations of dispersed sardines at twilight. The good agreement between measured and calculated resonance frequencies implies that effects of internal organs on compression of swim bladders of pelagic fish at this measurement site were small. If this inference can be shown to be generally valid, then prediction of resonance frequencies at other sites will be simplified.

Measured resonance frequencies of schools were shown to be consistent with theoretical calculations which assume that the separation between fish in school during daytime, when the majority of pelagic fish are generally in school, is approximately one fish length and that the number of fish per school is about 10^4. These inferences are consistent with previously published measurements of these parameters.

A model for calculating number densities and biomass averaged over mesoscale distances was developed. Inferred number densities and biomass at the Modal Lion site were shown to be comparable to estimates based on echo sounder data.

IMPACT/APPLICATION

Naval significance: This research suggests that the detection range of Naval tactical sonars may be significantly reduced when operating in shallow water environments where large numbers of pelagic fish are present. Strategically important areas where fish concentrations may be particularly high include the Yellow Sea, the Mediterranean Sea, the Black Sea, and the shallow seas off the west coast of the United States and the west coast of Europe. Since the Q of the resonance frequency averaged over ~ 12 km is about 2, combatants with sonars that operate at different frequencies (e.g., 3 and 4 kHz) could find themselves in situations where one may have a very long detection range, whereas the other may have a very short detection range in the same environment at the same time. Absorption losses also affect reverberation level. Effects due to bioacoustic absorptivity should be incorporated into performance prediction models, and in formulating environmental adaptation strategies of tactical sonars

Fisheries applications: These results suggest that bioacoustic absorptivity can be used to estimate number density (biomass) of pelagic fish with swimbladders in littoral environments, and to classify fish by length.

TRANSITIONS

ONR program manager, Ken Dial, has agreed to support purchase of low cost, large bandwidth, littoral, L^3, receiving and source arrays to enable the first, American, broad band, long term measurements of transmission loss between a fixed source and fixed receivers in littoral environments at sonar frequencies. Such measurements permit isolation of the effects of bioacoustic absorptivity, internal waves and other parameters on transmission loss. The criteria for such measurements are: 1) a fixed broadband source, and 2) a fixed, broadband receiving array, together with a long term recording (there have been only two measurements which have satisfied these criteria: David Weston, in the Bristol Channel in 1965; and Orest Diachok, in the Gulf of Lion in 1995).

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RELATED PROJECTS

Theoretical modeling of Modal Lion data was done in collaboration with SACLANT CENTRE (Dr. Carlo Ferla).

Biological sampling during Modal Lion was done by IFREMER, Sete, France. During my last visit to Sete (in September of 1997), the Technical Director and the principal investigator (Dr. Bernard Liorzou) agreed that IFREMER's remaining contribution to this research (estimation of the biomass of sardines at the Modal Lion site) will be completed in 1998.

Low cost, large bandwidth, light weight source and receiver arrays have been designed in co-operation with Dr. Bill Hodgkiss of the Marine Physical Laboratory of the Scripps Institute of Oceanography.

Experiments to evaluate the potential of this new technology for biomass assessment, and monitoring of the growth and mortality rates of juvenile and adult fish are being formulated in co-operation with Dr. Paul Smith of the Southwest Fisheries Science Center of NOAA's National Marine Fisheries Service.

PUBLICATIONS

Orest Diachok, "Bioacoustic resonance absorption spectroscopy", invited paper, Special Session on Acoustics of Fish, Fisheries and Plankton, Proceedings of the ICA / ASA Meeting in Seattle, 1998.

Orest Diachok and Paul Smith, "Monitoring the growth and mortality rates of pelagic fish with absorption spectroscopy measurements", Special Session on Acoustics of Fish Fisheries and Plankton, Proceedings of the ICA / ASA Meeting in Seattle, 1998.

Orest Diachok, "Fish absorption spectroscopy", in Proceedings of the Third European Conference on Underwater Acoustics, J. Papadakis, Editor, E.C. Press, 1996.

Orest Diachok and Carlo Ferla, “Measurement and simulation of the effects of absorptivity due to fish on transmission loss in shallow water”, Proceedings of the Oceans 96 Conference, IEEE Press, 1996.

Orest Diachok, “Absorption spectroscopy: a new approach to estimation of biomass”, an invited talk which was presented at the Meeting of the American Fisheries Society in 1997, will be published as a peer-reviewed paper in the book, “Marine Bioacoustics: Sustaining Global Fisheries One Ping at a Time”, Jay Kirsch, Editor, American Fisheries Society Press, 1998.

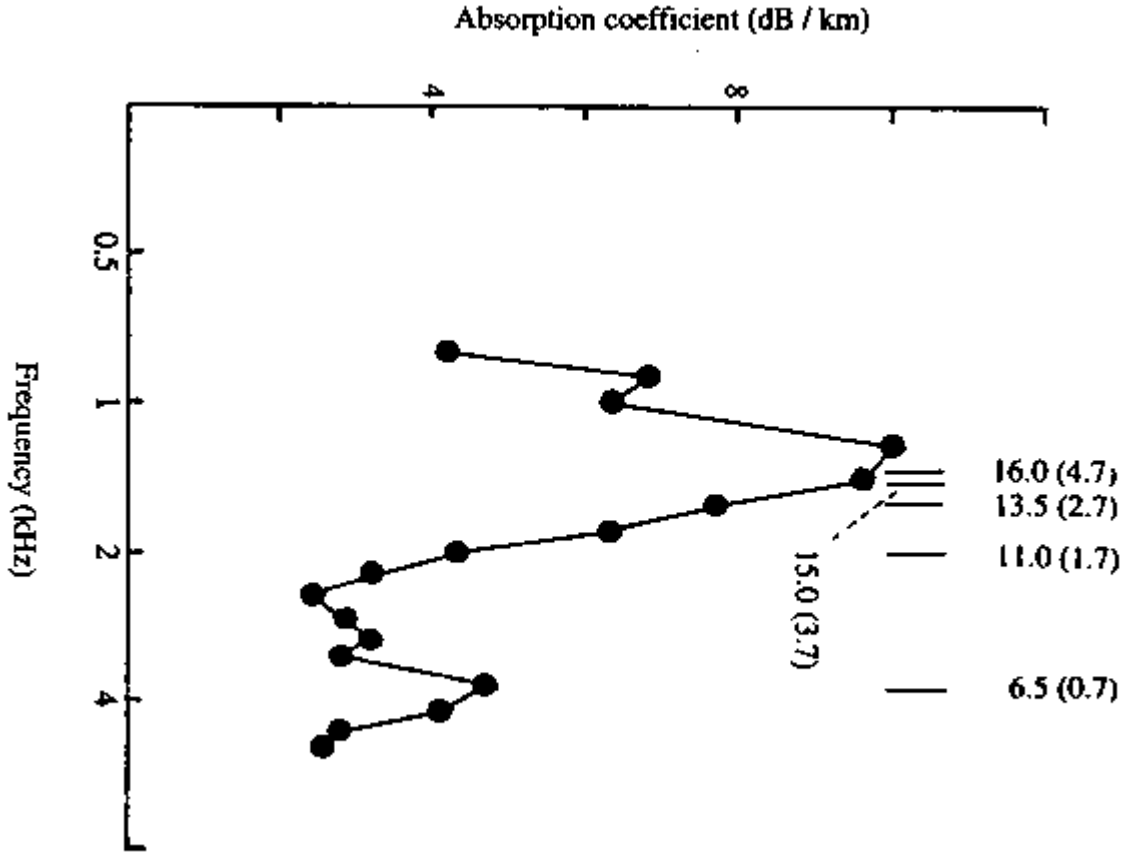
Orest Diachok, “Effects of absorptivity due to fish on transmission loss in shallow water”, accepted for publication in the Journal of the Acoustical Society of America.

Orest Diachok, “Bioacoustic Absorption Spectroscopy”, 1998 NRL Review, Naval Research Laboratory, Washington, D.C., 85-87, 1998.

Orest Diachok, “Resonance frequencies of absorption lines due to pelagic fish”, Proceedings of the 137th Meeting of the Acoustical Society of America, 1999.

PATENTS

I have submitted a patent application for my design of low cost, large bandwidth, light weight source and receiver arrays, specifically designed to permit bioacoustic absorption spectroscopy measurements between a fixed broadband source and multiple, widely spaced fixed receiving arrays in littoral seas. The Naval Research Laboratory has made a formal decision to apply for an international patent on my design.



Magnitudes of absorption coefficients derived from transmission loss measurements vs frequency on near surface hydrophones at night, and computed resonance frequencies of sardines of specified lengths (in cm) and ages (in years).